

Design of internet of things-integrated programmable logic controller for demonstrating automated sorting systems

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ABSTRACT

This project presents an automated workpiece sorting demonstration system controlled by a programmable logic controller (PLC) and a touch screen interface. The system integrates an internet of things (IoT) gateway that communicates with the PLC via Modbus remote terminal unit (RTU) over RS-485, allowing the transfer of digital data. This data is processed using JavaScript within the Node-RED platform to manage machine operations and display the operational status. The system supports both manual control and IoT-based management, enabling the sorting of cylindrical workpieces to designated areas. Metal and non-metal detection is achieved using capacitive and inductive sensors, respectively, which inform a stepper motor to manipulate the workpieces via a gripper pneumatic to the specified locations. Test results indicate a high detection capability of the sensors: the capacitive sensors achieved a 95% detection rate over 100 trials, while the inductive sensors recorded a 97% detection rate. Furthermore, the precision of placing workpieces at the target locations was 92% across 100 attempts. This system showcases an effective combination of automation and IoT technologies, improving efficiency in workpiece sorting processes.

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1. INTRODUCTION

The rapid advancement of technology in industrial automation has transformed traditional manufacturing processes, leading to increased efficiency, precision, and adaptability. One of the key components driving this evolution is the integration of internet of things (IoT) technologies with programmable logic controllers (PLCs) [1]-[3]. Automated sorting systems, essential in various sectors such as logistics, manufacturing, and recycling, stand to benefit significantly from this synergy. Automated sorting systems are designed to identify, classify, and separate items based on specific criteria, thereby enhancing operational efficiency and reducing manual labor. However, challenges such as real-time monitoring, data-driven decision-making, and remote control capabilities often limit the effectiveness of these systems. The incorporation of IoT

provides a solution by facilitating seamless communication between devices, enabling real-time data collection and analysis.

The design of IoT-integrated PLCs for automated systems has garnered significant attention in the context of Industry 4.0 [4] and smart manufacturing. Traditional PLCs, while reliable for deterministic industrial control, often lack native capabilities for remote monitoring, flexible data communication, and cloud integration. By integrating IoT technologies with PLCs, researchers and industry professionals aim to bridge this gap—enhancing system intelligence, real-time connectivity, and operational efficiency. Several studies have explored the incorporation of IoT into PLC-based automation. For instance, the use of Node-RED [5] as a lightweight and visual programming environment for IoT has been applied in small-scale industrial scenarios to demonstrate real-time control and dashboard monitoring. Other approaches utilize MQTT protocols [6] in combination with languages like OpenCv [7] and Python to allow scalable, publish-subscribe communication between PLCs and cloud servers or user interfaces. While supervisory control and data acquisition (SCADA) [8] systems continue to dominate large-scale industrial automation, they often come with higher implementation costs and complexity. In contrast, low-cost IoT gateways and open-source tools provide an accessible alternative for prototyping and educational environments. This aligns with the goal of the current research: to design and simulate an IoT-integrated PLC system for automated workpiece sorting, using cost-effective components while maintaining a functional level of industrial relevance. By combining hardware such as Amsamotion FX3U PLCs, pneumatic actuators, and sensors, with IoT communication tools like HF2211 gateways and Node-RED, this research demonstrates how IoT-enhanced PLCs can be applied in a real-time, flexible automation scenario. The proposed system not only highlights the feasibility of such integration but also provides a practical reference for future development in smart control systems.

Node-RED software is a powerful, open-source, flow-based development tool designed to simplify the integration and management of IoTs devices, APIs, and web services. Built on Node.js, it provides a visual programming environment that allows users to create applications by wiring together various nodes, each representing a specific function or data source. The platform's user-friendly interface enables both technical and non-technical users to build complex workflows with minimal coding. Node-RED supports a wide array of protocols, including MQTT, HTTP, and WebSocket, making it versatile for different applications from home automation to industrial IoT solutions [9]-[11]. Users can easily extend functionality through a rich library of community-contributed nodes and create custom dashboards for real-time data visualization. With its real-time processing capabilities and ease of integration, Node-RED empowers developers to rapidly prototype, test, and deploy IoT applications, fostering innovation across various domains. Its growing community and extensive documentation further enhance its accessibility, making Node-RED a popular choice for both hobbyists and professionals in the IoT space.

The objective of this study is to present a comprehensive framework for simulating IoT-based control of automated sorting systems using PLCs. We aim to showcase the potential benefits, including increased accuracy, reduced sorting times, and enhanced system responsiveness. The insights gained from this simulation will provide valuable contributions to the field of smart manufacturing and Industry 4.0, ultimately paving the way for more intelligent and interconnected industrial systems. We used Node-RED in our research because it is well-suited for IoT, smart home applications, rapid prototyping, and edge automation—particularly in a laboratory setting [12]. However, when building a large-scale industrial system, SCADA would be more appropriate. For developers seeking full control and flexibility, combining Python with MQTT is a robust approach [13]-[15]. Table 1 presents a comparison of IoT platforms for IoT-based control systems.

Table 1. Comparative analysis of Node-RED, MQTT+Python, and SCADA

Feature	Node-RED	MQTT + Python	SCADA
Coding required	No (low-code)	Yes	No (but vendor-specific)
Ease of use	★★★★	★★	★★
Cost	Free	Free	Expensive
industrial use	Medium	Medium	High
Integration with modern tech	★★★★	★★★	★
Real-time dashboard	Built-in	Manual	Built-in
Reliability	Good	Depends	Very high

The structure of this paper is as follows: the article first presents a preliminary introduction to IoT-based control of automated sorting systems using PLCs. Section 2 introduces the research materials proposed. Section 3 presents the proposed method and experimental process. Section 4 presents the results and discusses the evaluation of the IoT-based automated sorting system controlled by a PLCs. Finally, section 5 concludes the paper.

2. MATERIALS OF PROPOSED

This research separates the mechanism and control system into two distinct components. The first component is the mechanism, illustrated in Figure 1, which as shown in Figure 1(a) consists of a sorting system with three pneumatic cylinders and one stepper motor for positioning. The second component is the control unit, which includes a power supply, a PLC (Amsamotion FX3U), and an IoT gateway model HF2211. Figure 1(b) presents the AMX-FX3U-26MT-E, a low-cost module compatible with the Mitsubishi MELSEC series [16] of PLCs. This transistor-output PLC features 2 analog inputs, 1 analog output, 16 digital inputs, and 10 digital outputs. It also supports ethernet Modbus communication [17], allowing it to connect with other devices on a network and exchange data. Additionally, we used the HF2211, a low-cost serial device server that enables bidirectional transparent transmission between RS232/RS485/RS422 and Wi-Fi/ethernet.

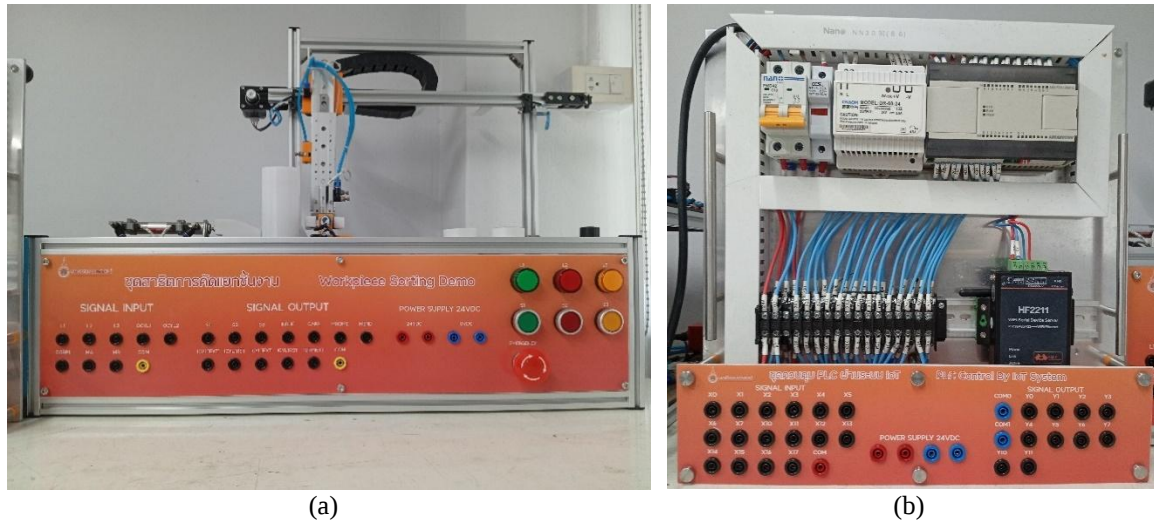


Figure 1. 3D model design of the PLC control set and structural components; (a) the sorting system hardware and (b) the control system with PLC and IoT module

The block diagram of the overall circuit architecture is shown in Figure 2. It includes five reed switches installed on the pneumatic cylinders and the gripper [18], [19]. These switches, along with inductive and capacitive proximity sensors and limit switches [20] are connected to the input of the PLC, which receives commands from the computer and the HF2211 Wi-Fi server. The PLC serves as the main control program for the process system and drives the actuators through the output devices.

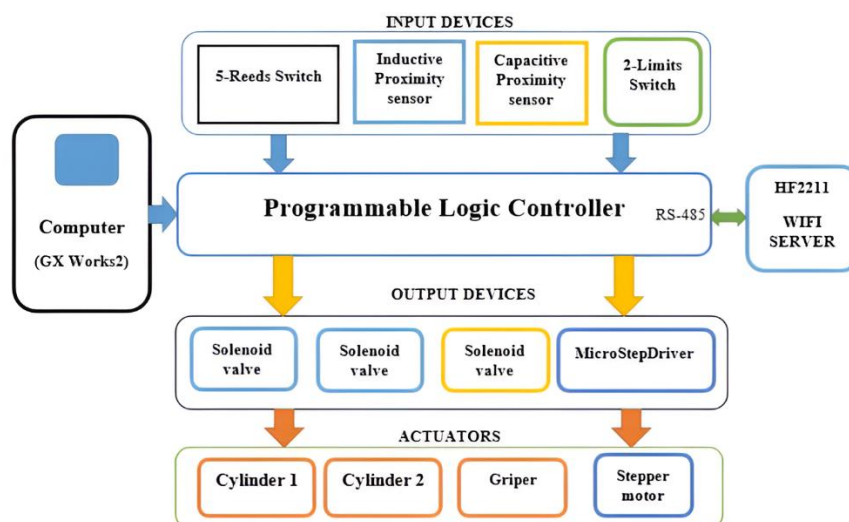


Figure 2. Block diagram of the overall circuit architecture illustrating the process

Figure 3 shows the hardware setup for the real experiment. The input and output circuits of the devices were connected to the terminals of the PLC according to the I/O addresses specified in Table 1. This table provides the names of the devices and their connection points for the entire system, corresponding to the ladder logic programming used to control the overall process.

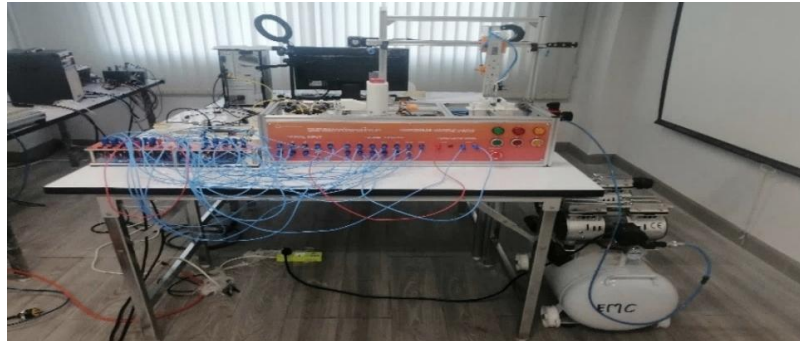


Figure 3. Hardware setup for the experiment

Figure 4 illustrates the integration of a PLC with IoT gateway, enabling smart monitoring, control, and data processing via cloud services [20]-[22]. The sensors include:

- Capacitive proximity sensor: detects non-metal objects, such as plastic or liquid, without direct contact.
- Inductive proximity sensor: detects metal objects using electromagnetic fields.
- Position sensor: detects the position or movement of mechanical components.

These sensors send signals to the PLC, which serves as the core controller that processes inputs from the sensors and executes pre-programmed logic to control outputs. The PLC controls actuators such as:

- Stepper motor: provides precise position control [23].
- Pneumatic cylinders: used for mechanical motion through compressed air [24].

The IoT gateway acts as a bridge between the PLC and the cloud, converting industrial protocols into IoT-friendly formats and enabling data transmission to remote servers. The cloud stores and analyzes data received from the IoT gateway. It can be used for data logging, analytics, predictive maintenance, and more. The user interface allows users to monitor the system in real-time, providing dashboards, and control panels. It can be accessed via web or mobile applications [25], [26].

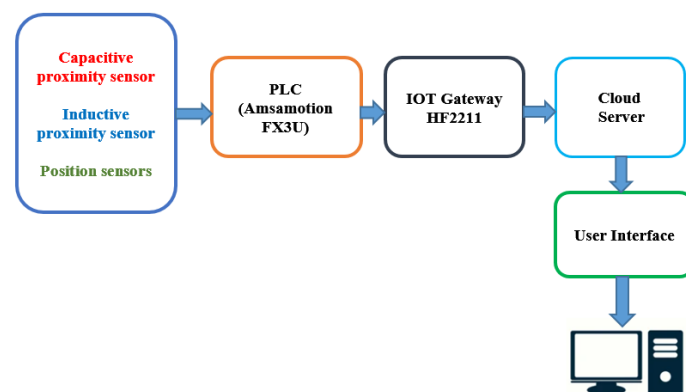


Figure 4. Block diagram of the IoT-integrated PLC architecture

Figure 5 shows the hardware installation and identifies the names of the hardware positions in the demonstrated automated sorting system. Figure 6 shows the block diagram of the electric and signal control wiring for all hardware connections. Table 2 contains important information for writing the ladder program, specifying the input and output positions for the PLC and providing detailed information about the devices and their respective locations.

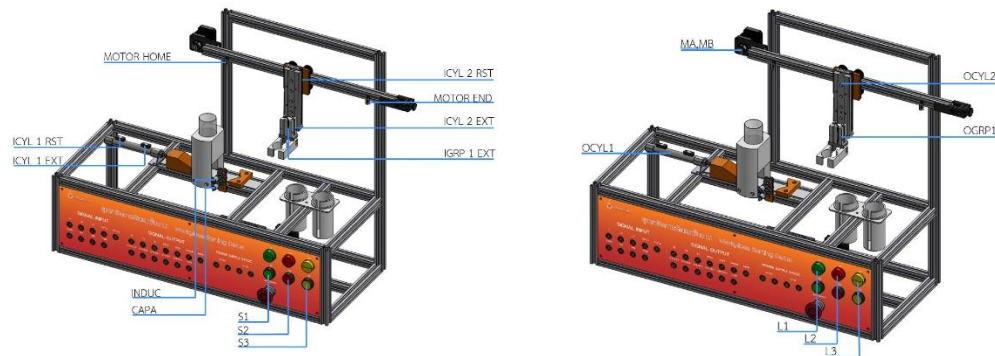


Figure 5. Hardware setup for the experiment

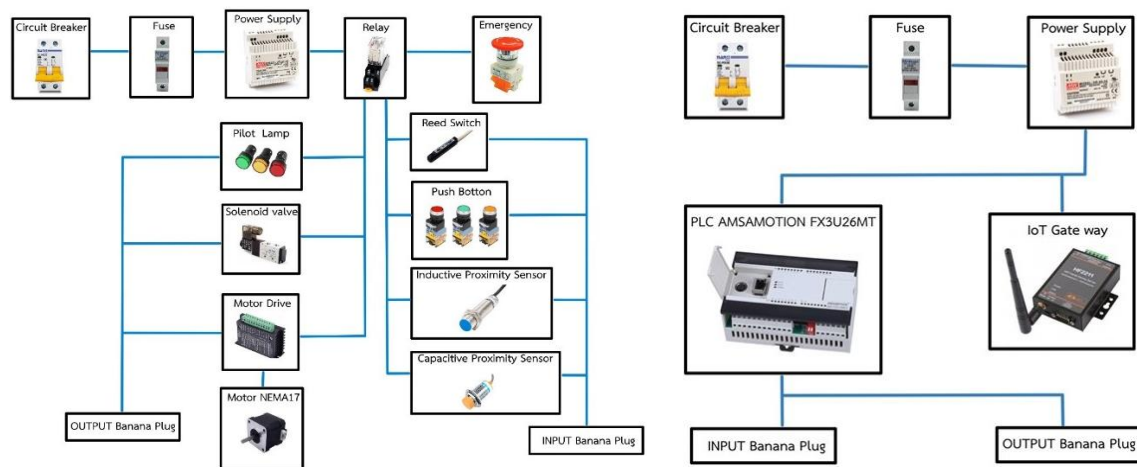


Figure 6. Block diagram of electric and signal control wiring

Table 2. The I/O addresses of devices connected to the PLC

Type	Symbol	Description	Address
Input	S1	Switch START	X0
	S2	Switch STOP	X1
	S3	Switch RESET	X2
	Induc	Inductive proximity sensor	X3
	Capa	Capacitive proximity sensor	X4
	M HOME	Motor HOME	X5
	M END	Motor END	X6
	ICYL 1 EXT	Input Cylinder 1 EXT	X7
	ICYL 1 RST	Input Cylinder 1 RST	X10
	ICYL 2 EXT	Input Cylinder 2 EXT	X11
	ICYL 2 RST	Input Cylinder 2 RST	X12
	IGRP 1 EXT	Input Gripper 1 EXT	X13
Output	MA	Motor A	Y0
	L1	Lamp green	Y1
	L2	Lamp red	Y2
	L3	Lamp yellow	Y3
	MB	Motor B	Y4
	OCYL 1	Output Cylinder 1	Y5
	OCYL 2	Output Cylinder 2	Y6
HF2211	OGRP 1	Output Gripper 1	Y7
	B	DATA	D-
	A	DATA	D+

3. METHOD PROPOSED

The experimental procedure for this IoT-based workpiece sorting demonstration set is designed to show the working steps. We have created a flowchart outlining the process, as shown in Figure 7. The experimental approach is presented in the following subtopics in sequence.

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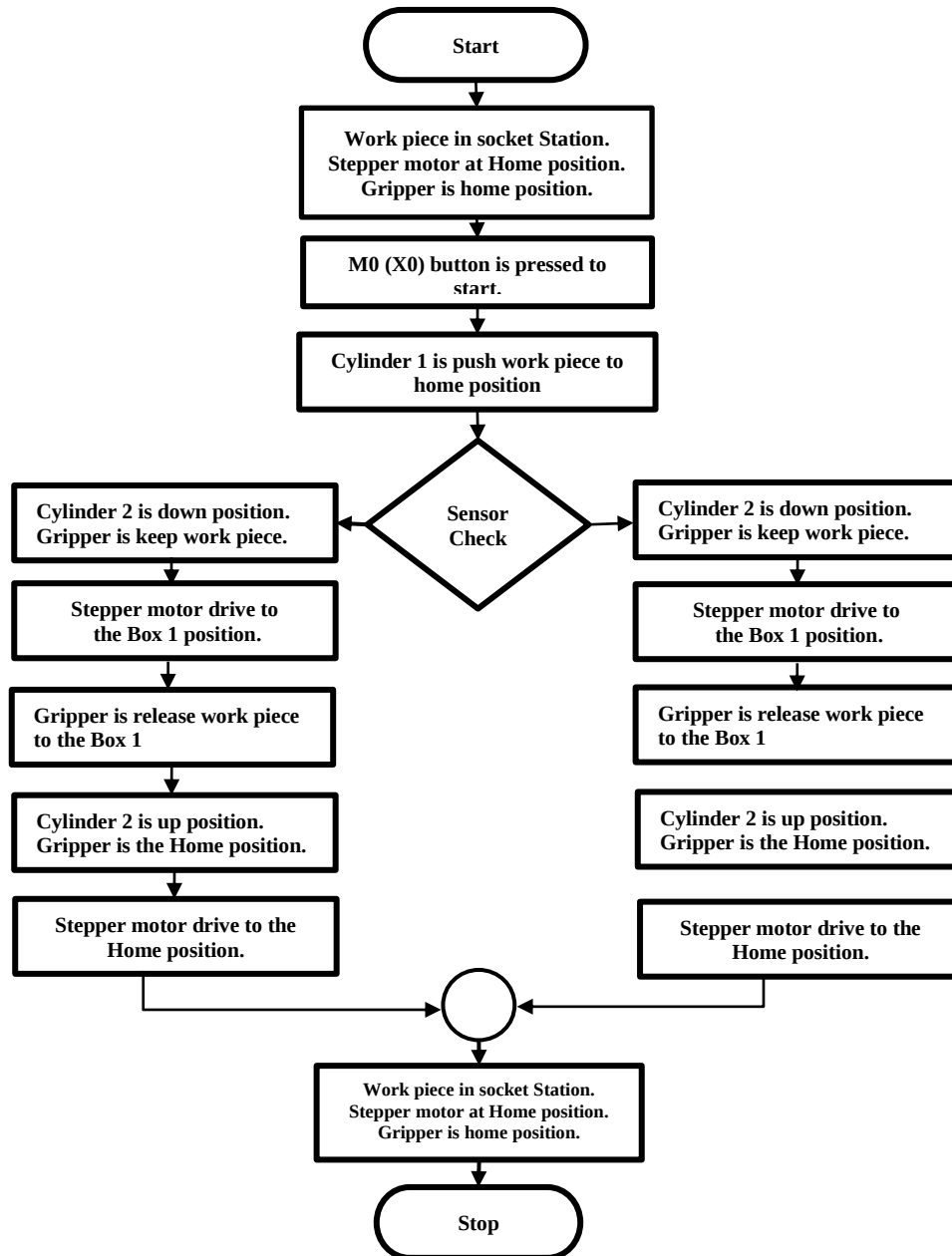


Figure 7. Flowchart of the process control system

3.1. Position setting of stepper motor drive with manual control

The position control of the gripper, which is driven along the Y-axis by a stepper motor, is shown in Figure 5. The block diagram illustrates a PLC that receives command signals and feedback from limit switches, which are set to restrict movement to the home position and the endpoint. The PLC then sends control signals to the microstep drive board to rotate the stepper motor to the desired position. Table 3 defines the PLC addresses required for writing the ladder program.

We used GX Works2 software to create the ladder diagram shown in Figure 8, which controls the speed and position of the stepper motor. Pressing switch S1 commands the stepper motor to rotate and drive the conveyor belt, moving cylinder 2 to the position at Box 2. Pressing switch S2 moves cylinder 2 to the position at Box 1. When switch S3 is pressed, the motor returns cylinder 2 to the home position and resets all values to their defaults. Figure 7 shows the ladder diagram used to control the stepper motor drive via three inputs labeled X0, X1, and X2. Input X0 corresponds to S1 and moves cylinder 2 to Box 2; X1 corresponds to S2 and moves it to Box 1; and X2 corresponds to S3, returning it to the home position and resetting all values to default.

Table 3. Specification I/O address for manual control of stepper motor

Input		Output	
Symbol	Address	Symbol	Address
S1	X0	MA(MotorA)	Y0
S2	X1	MB(MotorB)	Y4
S3	X2		

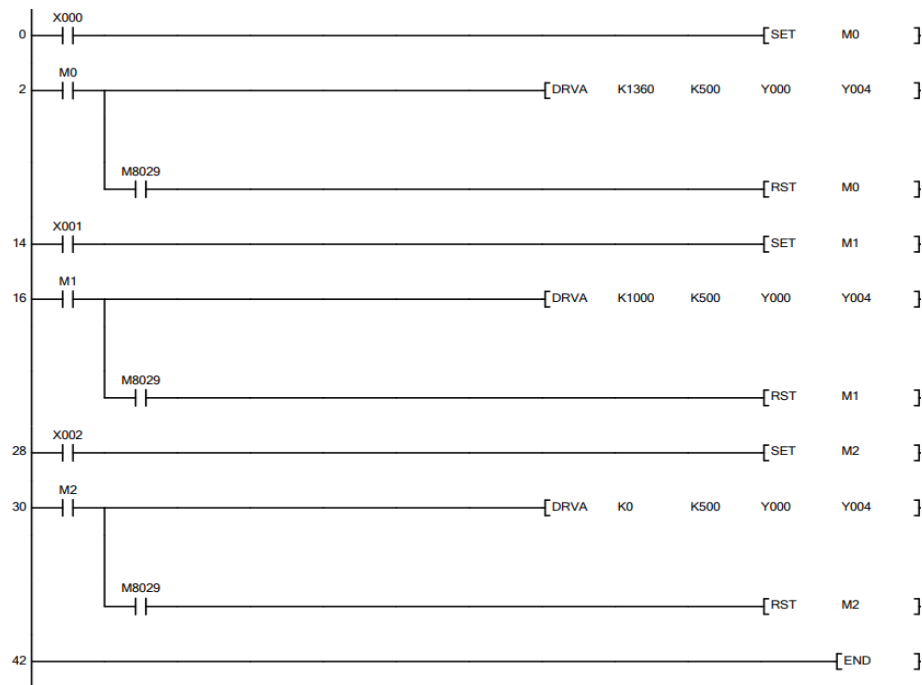


Figure 8. A part of the ladder diagram for controlling the stepper motor drive

The command to control the stepper motor's movement to any desired position is shown in Figure 9. Figure 9(a) adjusts the pulse position to K0, the speed of the stepper motor to K500 (pulses per second), the pulse output to Y0, and the direction output to Y4, with the following command: [DRVA K0 K500 Y0 Y4]. Figure 9(b) adjusts the pulse position to K1000, the speed of the stepper motor to K500 (pulses per second), the pulse output to Y0, and the direction output to Y4, with the following command: [DRVA K1000 K500 Y0 Y4]. Figure 9(c) adjusts the pulse position to K1360, the speed of the stepper motor to K500 (pulses per second), the pulse output to Y0, and the direction output to Y4, with the following command: [DRVA K1360 K500 Y0 Y4].

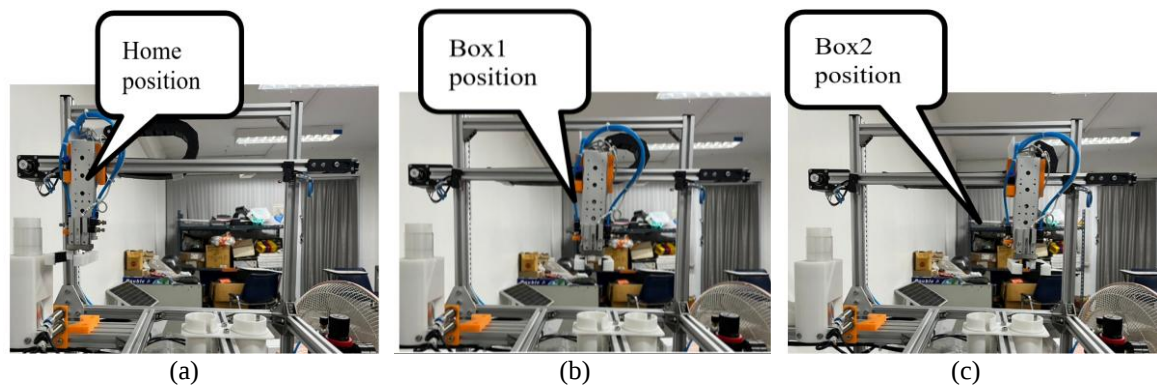


Figure 9. Hardware setup for the experiment; (a) the home position for the gripper, (b) the gripper at Box 1 position, and (c) the gripper at Box 2 position

3.2. Setup for controlling a stepper motor using the Node-RED platform

Before writing the control program using the PLC and Node-RED to manage and remotely display the prototype sorting system, Figure 6 illustrates the electrical wiring between the devices and the control unit, detailing the connections for the input and output circuits of the PLC and the HF2211 Wi-Fi server. This section focuses on stepper motor control by the PLC. Table 4 defines the PLC addresses required for writing the ladder program.

Table 4. Specification connect port

Address	Devices
M0	BOX2
M1	BOX1
M2	HOME MOTOR

The Modbus remote terminal unit (RTU) communication [27] is the exchange of data between the Master and Slave, where the PLC is set as the Slave, and Node-RED, connected to the HF2211, is configured as the Master. To use GX Works2 to set the PLC as a Slave, you need to add certain code to the PLC to enable Modbus RTU RS485 communication.

The commands written as follows:

- MOV H181 D8420; set PLC communication parameters: Slave, data bits=8, parity=None, stop bit=1, baud rate=9600, protocol=Modbus, and mode=RTU.
- MOV K2 D8200; set PLC as Slave MOV K2 D8434; set PLC as Slave number 2.
- MOV H8080 D8480; read/write M (data memory).

Figure 10 shows the code to upload for setting the PLC as a Slave and configuring the communication settings.



Figure 10. Ladder diagram for setting the PLC as a Slave

3.3. Designing the ladder diagram for the process control system using the Node-RED platform

The setting up the IoT gateway model HF2211 requires the IoT service program to configure various settings. Check the PLC control system's status through the IoT system to ensure the RS485 connection between the PLC and HF2211 is correct. Verify that D+ is connected to A, and D- is connected to B, as shown in Figure 11. Users should connect to the HF2211 by enabling their phone's hotspot, naming it 'HF2211' with the password '12345678.' Set the IP address of the laptop or PC to be in the 200 subnet, such as 192.168.200.10.

To make the workpiece sorting demonstration set show operational status and control the basic machine functions through the IoT system, it is necessary to write a ladder program to configure the PLC as a Slave and enable Modbus RTU RS485. This will allow the PLC to send and receive Modbus RTU signals via RS485. The control system operation steps are as follows:

- Check that the conveyor belt with pneumatic cylinder 2 is at the HOME position before starting the operation.
- When pressing the M0 button once, L1 will turn on, and pneumatic cylinder 1 will push the workpiece to the sorting waiting position. A sensor will check whether the workpiece is metal or non-metal.

- After checking the workpiece, pneumatic cylinder 2 will pick up the workpiece and place it in Box 1 or Box 2. The condition is that the metal workpiece will be placed in Box 1, and the non-metal workpiece will be placed in Box 2.
- After placing each workpiece, the conveyor belt with pneumatic cylinder 2 will return to the HOME position to wait for the next command.
- Set the system to stop after placing 2 workpieces, turn off L1, and make L3 blink once per second.
- To start a new operation, press M1 twice to turn off L3, then press M2 twice to turn on L1, allowing the system to start a new operation.
- Test the system operation.

Figure 12 shows a control process system using IoT. Figure 12(a) shows the website design through Node-RED, which can be done using the Node-RED dashboard, a tool that allows you to create an interface (UI) for websites or IoT applications. Figure 12(b) shows the JavaScript programming through Node-RED to control the operation of the simulated workpiece sorting system, which operates through a web interface.

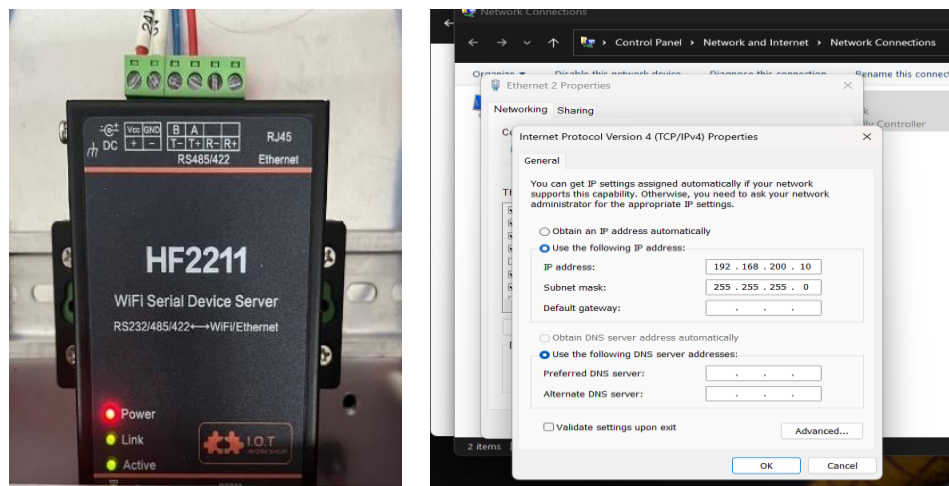


Figure 11. The configuration of the HF2211

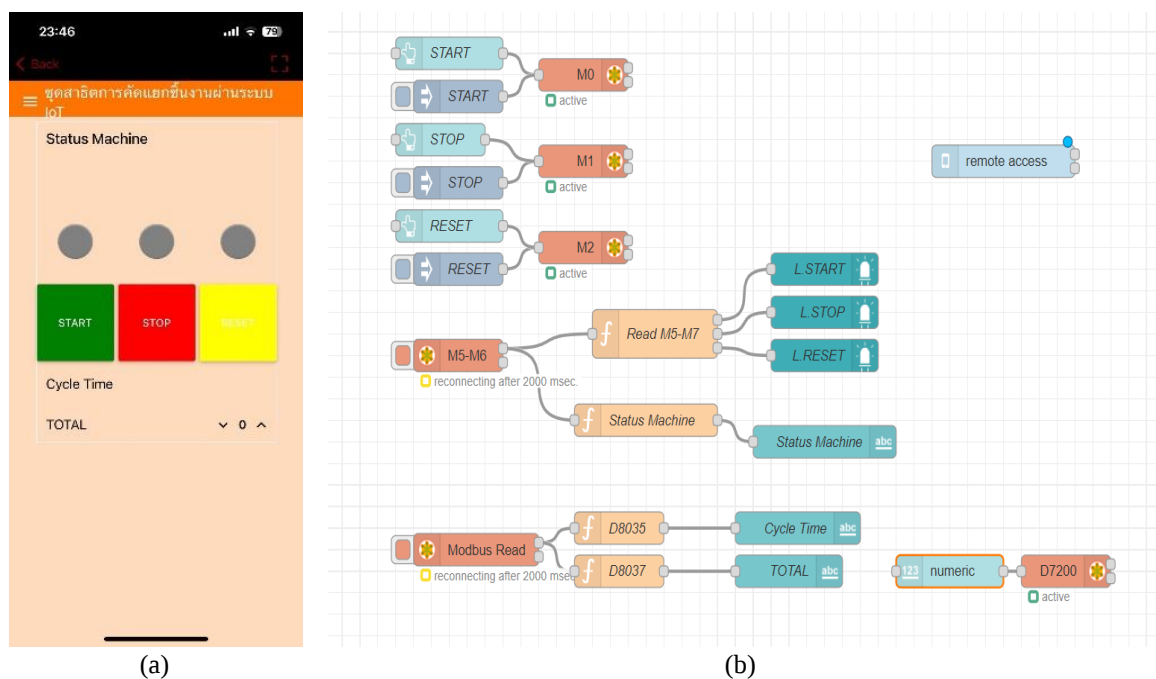


Figure 12. Control of the process system using IoT; (a) website design through Node-RED and (b) writing JavaScript to design a website through Node-RED

4. RESULTS AND DISCUSSION

This section presents the results obtained from the demonstration of the IoT-based automated sorting system controlled by a PLC. The evaluation results of the performance of the workpiece sorting demonstration set via the IoT system with ladder diagram programming are shown in Figure 13. Figure 13(a) shows the gripper in the home position. Figure 13(b) shows the metal detector sensor detecting metal, prompting the gripper to move down and pick up the metal workpiece. Figure 13(c) shows the gripper moving down to pick up the metal workpiece, then moving to Box 1 to place the workpiece into Box 1. Figure 13(d) shows the gripper moving back to the home position to wait for the next workpiece. Figure 13(e) shows the non-metal detector sensor detecting non-metal, prompting the gripper to move down and pick up the non-metal workpiece. Figure 13(f) shows the gripper moving down to pick up the non-metal workpiece, then moving to Box 2 to place the workpiece into Box 2.

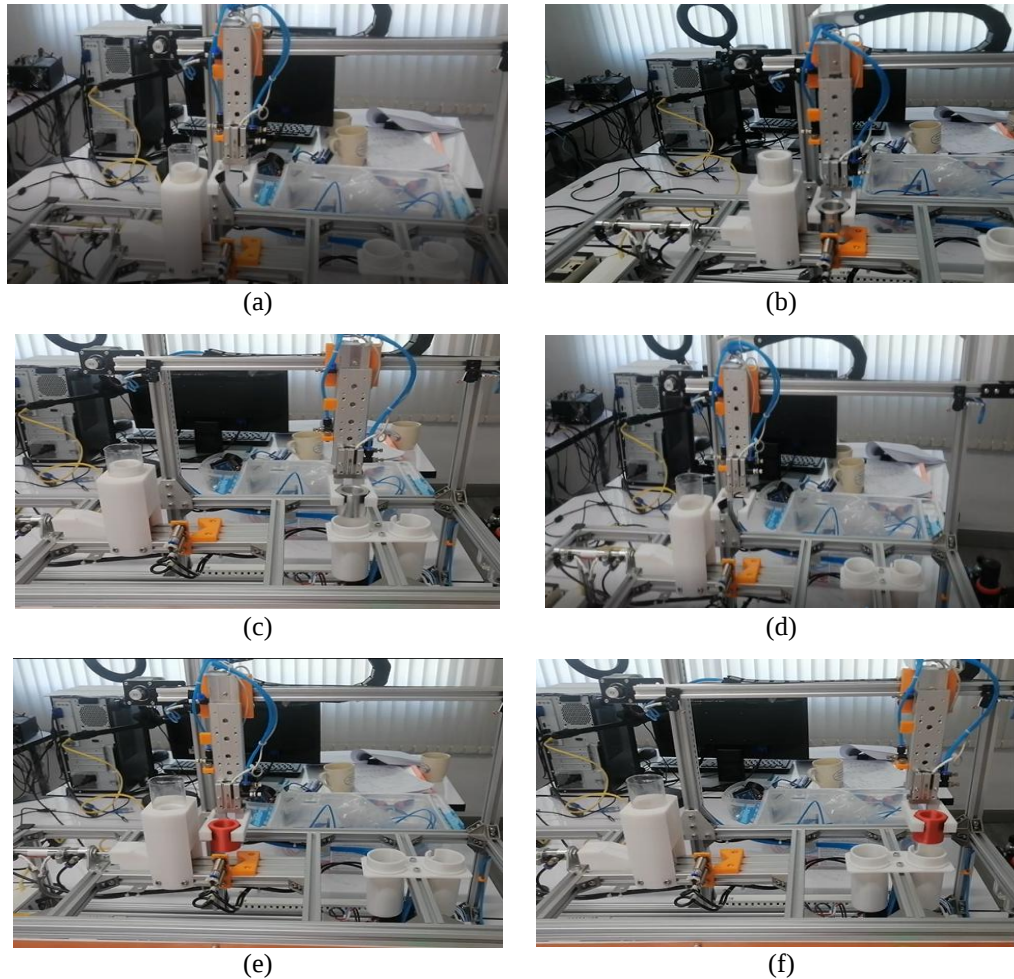


Figure 13. Results from the control based on the specified conditions; (a) at home position, (b) gripper pickup metal work piece, (c) move to Box 1 position, (d) return to home position, (e) pick up non-metal, and (f) go to Box 2 position

Table 5 presents the tests conducted to evaluate the performance of the demonstration system for sorting workpieces using IoT technology. A total of 100 metal workpieces were sorted, with the capacitive sensor successfully detecting 95 and failing to detect 5, resulting in a detection efficiency of 95%. For 100 non-metal workpieces, the inductive sensor successfully detected 97 and missed 3, yielding a detection efficiency of 97%. Additionally, when workpieces were placed in the designated position 100 times, the system correctly positioned them 92 times and failed 8 times, resulting in a positioning efficiency of 92%.

From the statistical analysis of the experimental data presented in Table 4, the findings can be summarized as follows: the formulas used include the mean, standard deviation, and 95% confidence interval. The bar chart illustrated in Figure 14 shows the performance of the sensors and the accuracy of workpiece

placement in the demonstration system. The inductive sensor outperforms the capacitive sensor in terms of both accuracy and consistency, as it has fewer undetected instances. The number of correctly placed workpieces remains high overall, though a few instances of incorrect placement were observed. The visual comparison confirms that, while both sensors are effective, the Inductive sensor provides slightly more reliable detection, which contributes positively to the overall placement accuracy.

Table 5. Performance test results of the demonstration system for sorting workpieces via IoT

Test instance	Detect by capacitive proximity sensor		Detect by inductive proximity sensor		Placed in the correct position (pieces)	Not placed in the correct position (pieces)
	Detected (pieces)	Not detected (pieces)	Detected (pieces)	Not detected (pieces)		
1-10	10	-	10	-	10	-
11-20	10	-	10	-	10	-
21-30	10	-	9	1	9	1
31-40	10	-	10	-	10	-
41-50	9	1	10	-	9	1
51-60	10	-	9	1	9	1
61-70	9	1	10	-	9	1
71-80	9	1	9	1	8	2
81-90	10	-	10	-	10	-
91-100	8	2	10	-	8	2
Net	95	5	97	3	92	8
Percent (%)	95	5	97	3	92	8

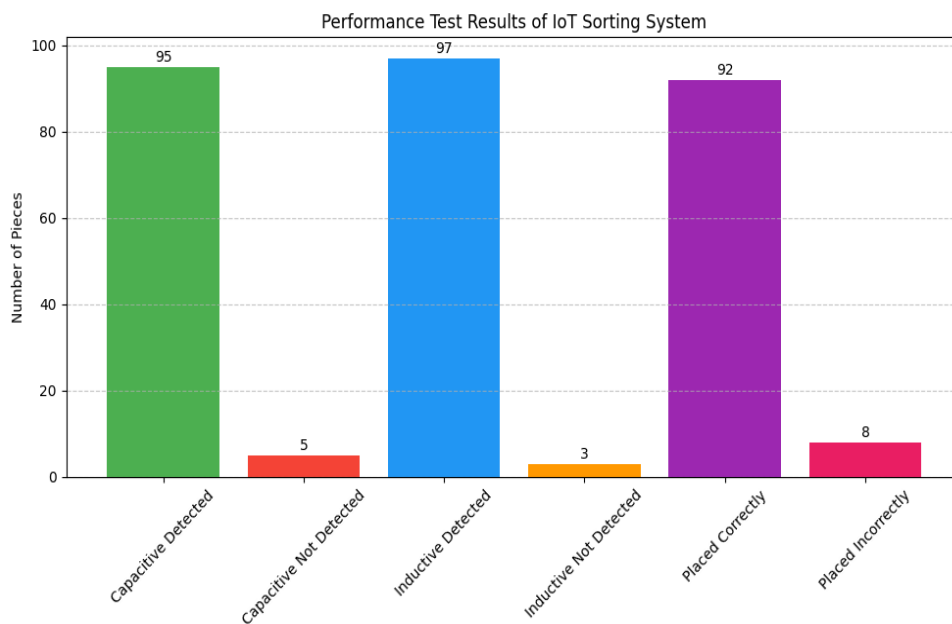


Figure 14. The performance efficiency of the demonstration system for sorting workpieces via IoT

From the statistical analysis of the experimental data presented in Table 4, the findings can be summarized as follows: the formulas used include the mean, standard deviation, and 95% confidence interval. The bar chart illustrated in Figure 14 shows the performance of the sensors and the accuracy of workpiece placement in the demonstration system. The inductive sensor outperforms the capacitive sensor in terms of both accuracy and consistency, as it has fewer undetected instances. The number of correctly placed workpieces remains high overall, though a few instances of incorrect placement were observed. The visual comparison confirms that, while both sensors are effective, the Inductive sensor provides slightly more reliable detection, which contributes positively to the overall placement accuracy.

Table 6 shows the statistical summary of sensor detection and workpiece placement, which can be analyzed as follows: the inductive sensor has the lowest variance, indicating that it provides the most consistent detection results. The correct placement shows the highest variance, suggesting potential uncertainty in the placement process. All three categories have relatively narrow confidence intervals, indicating that the test results are fairly accurate and reliable.

Table 6. Statistical summary of sensor detection and workpiece placement accuracy

Category	Mean (pieces)	Standard deviation	95% confidence interval
Capacitive proximity sensor	9.5	0.71	(8.99, 10.01)
Inductive proximity sensor	9.7	0.48	(9.35, 10.05)
Correct placement of workpieces	9.2	0.79	(8.64, 9.76)

5. CONCLUSION

The results from testing the operation of the prototype sorting system, which was designed and built with components controlled by a PLC managing the operation of pneumatic cylinders and stepper motors via the IoTs, demonstrate that we can study and design production processes and self-inspect workpieces using modern technology. This prototype can serve as a guideline for use in production and inspection systems in the industrial sector, yielding satisfactory results.

The design of an IoT-integrated PLC for demonstrating automated sorting systems represents a significant advancement in industrial automation. By combining IoT technology with traditional PLCs systems, this design enhances the functionality, flexibility, and scalability of sorting operations. The integration allows for real-time monitoring, remote control, and data analysis, leading to increased efficiency, reduced downtime, and better decision-making.

Furthermore, the use of IoT enables the system to be more adaptable to changing requirements and provides valuable insights into system performance through data-driven feedback. This approach not only streamlines the sorting process but also paves the way for smarter, more connected manufacturing and logistics environments. The successful implementation of this IoT-PLC system demonstrates the potential of integrating cutting-edge technologies into industrial automation, ultimately contributing to the development of more efficient, sustainable, and cost-effective solutions for modern industries.

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AUTHOR CONTRIBUTIONS STATEMENT

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M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The research related to animal use has been complied with all the relevant national regulations and institutional policies for the care and use of animals.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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